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Tuesday, February 15, 2011

Some speculations on the frontier below our feet

The biggest problem we face with the frontier below that we're literally in the dark. We have a number of crude geophysical techniques (seismology, gravity field, electromagnetic, etc.) but none of them allow creating a detailed map like we can make of the surface of a distant moon of Saturn or even of a cloud-covered planet like Venus. So in some important ways we are more ignorant of the ground a few hundred meters down in most places on our own planet than we are of the surface of most of the other planets and moons in our solar system. We know less about the distribution of the common molecules below the earth's crust, only 35 kilometers below our feet, than we do of the distribution of those molecules on the surfaces of dust clouds in distant galaxies.

One possible fix to this earth-blindness is the neutrino, and more speculatively and generally, dark matter. We can detect neutrinos and anti-neutrinos by (I'm greatly oversimplifying here, physicists please don't cringe) setting up big vats of clear water in complete darkness and lining them with ultra-sensitive cameras. The feature of neutrinos is that they rarely interact with normal matter, so that most of them can fly from their source (nuclear reactions in the earth or sun) through the earth and still be detected. The bug is that almost all of them fly through the detector, too. Only a tiny fraction hit a nucleus in the water and interact, giving off a telltale photon (a particle of light) which is picked up by one of the cameras. It is common now to detect neutrinos from nuclear reactors and the sun, and more recently we have started using some crude instruments to detect geo-neutrinos (i.e. neutrinos or anti-neutrinos generated by the earth not the sun). With enough vats and cameras we may be able to detect enough of these (anti-)neutrinos from nuclear reactions (typically radioactive decays) in the earth's crust to make a detailed radioisotope map (and thus go a long way towards a detailed chemical map) of the earth's interior. For the first time we'd have detailed pictures of the earth's interior instead of very indirect and often questionable inferences. A 3D Google Earth. These observatories may also be a valuable intelligence tool, detecting secret nuclear detonations and reactors being used to construct nuclear bomb making material, via the tell-tale neutrinos these activities give off.

Other forms of weakly interacting particles, the kind that probably make up dark matter, may be much more abundant but interact even more weakly than neutrinos. So weakly we haven't even detected them yet. They're just the best theory we have to explain why galaxies hang together: if they consisted only of the visible matter they should fly apart. Nevertheless, depending on what kinds of dark particles we discover, and on what ways they weakly interact with normal matter, we may find more ways of taking pictures of the earth's interior.

What might we find there? One possibility: an abundance of hydrogen created by a variety of geological reactions and sustained by the lack of oxygen. Scientists have discovered that the predominant kinds of rocks in the earth's crust contain quite a bit of hydrogen trapped inside them: on average about five liters of hydrogen per cubic meter of rock. This probably holds at least to the bottom of

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the lithosphere. If so that region contains about 150 million trillion liters of hydrogen.

Sufficiently advanced neutrino detectors might be able to see this hydrogen via its tritium, which when it decays gives off a neutrino. Tritium with its half-life of about 12 years is very rare, but is created when a more common hydrogen isotope, deuterium, captures a neutrino from a more common nuclear event (the decay of radioisotopes that are common in the earth's crust). About one-millionth of the deuterium in the heavy water moderating a nuclear reactor is converted into tritium in a year. This rate will be far less in the earth's interior but still may be significant enough compared to tritium's half-life that a sufficiently sensitive and calibrated (with respect to the much greater stream of such neutrinos coming from the sun) neutrino detector of the future may detect hydrogen via such geotritium-generated neutrinos. However, the conversion of deuterium to tritium in the earth's core may be so rare that we will be forced to infer the abundance of hydrogen from the abundance of other elements. Almost all elements have radioisotopes that give off neutrinos when they decay, and most of these are probably much more common in the earth's core than tritium.

Another possibility for detecting hydrogen is, instead of looking for geo-neutrinos, to look at how the slice of earth one wants to study absorbs solar neutrinos. This would require at least two detectors, one to look at the (varying) unobstructed level of solar neutrinos and the other lined up so that the geology being studied is between that detector and the sun. This differential technique may work even better if we have a larger menagerie of weakly interacting particles ("dark matter") to work with, assuming that variations in nuclear structure can still influence how these particles interact with matter.

It's possible that a significant portion the hydrogen known to be locked into the earth's rocks has been freed or can be freed merely by the process of drilling through that rock, exposing the highly pressurized hydrogen in deep rocks to the far lower pressures above. This is suggested by the Kola Superdeep Borehole, one of those abandoned Cold War super-projects. In this case instead of flying rockets farther than the other guy, the goal was to drill deeper than the other guy, and the Soviets won this particular contest: over twelve kilometers straight down, still the world record. They encountered something rarely encountered in shallower wells: a "large quantity of hydrogen gas, with the mud flowing out of the hole described as 'boiling' with hydrogen."

The consequences of abundant geologic hydrogen could be two-fold. First, since a variety of geological and biological processes convert hydrogen to methane (and the biological conversion, by bacteria appropriately named "methanogens", is the main energy source for the deep biosphere, which probably substantially outweighs the surface biosphere), it suggests that our planet's supply of methane (natural gas) is far greater than of oil or currently proven natural gas reserves, so that (modulo worries about carbon dioxide in the atmosphere) our energy use can continue to grow for many decades to come courtesy of this methane.

Second, the Kola well suggests the possibility that geologic hydrogen itself may become an energy source, and one that frees us from having to put more carbon dioxide in the atmosphere. The "hydrogen economy" some futurists go one about, consisting of fuel-cell-driven machinery, depends on *making* hydrogen which in turn requires a cheap source of electricity. This is highly unlikely unless we figure out a way to make nuclear power much cheaper. But by contrast geologic hydrogen doesn't have to be made, it only has to be extracted and purified. If just ten percent of the hydrogen in the lithosphere turns out to be recoverable over the next 275 years, that's enough by my calculations to enable a mild exponential growth in energy usage of 1.5%/year over that entire period (starting with the energy equivalent usage of natural gas today). During most of that period human population is expected to be flat or falling, so practically that entire increase would be in per capita usage. To put this exponential growth in perspective, at the end of that period a person would be consuming, directly or indirectly, about 330 times as much hydrogen energy as they consume in natural gas energy today. And since it's hydrogen, not hydrocarbon, burning it would not add any more carbon to the atmosphere, just a small amount of water.

Luckily our drilling technology is improving: the Kola well took nearly two decades to drill at a leisurely pace of about 2 meters per day. Modern oil drilling often proceeds at 200 meters/day or higher, albeit not to such great depths. Synthetic diamond, used to coat the tips of the toughest drills, is much cheaper than during the Cold War and continues to fall in price, and we have better materials for withstanding the high temperatures and pressures encountered when we get to the bottom of the earth's crust and proceeding into

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the upper mantle (where the Kola project got stymied: their goal was 15 kilometers down).

A modern drill bit studded with polycrystalline diamond

Of course, I must stress that the futuristic projections given above are quite speculative. We may not figure out how to affordably build a network of neutrino detecting vats massive enough or of high enough precision to create detailed chemical maps of the earth's interior. And even if we create such maps, we may discover not so much hydrogen, or that the hydrogen is hopelessly locked up in the rocks and that the Kola experience was a fluke or misinterpretation. Nevertheless, if nothing else this exercise shows, despite all the marvelous stargazing science that we have done, how much mysterious ground we have below our shoes.

Posted by Nick Szabo at 9:02 PM

1 comment:

Bitpeddler said...

There are appear to be all sorts of angles on this:

* Coherent neutrino scattering
* Neutrino Moessbauer effect and other exotic effects
* New neutrino sources and detection techniques
* Geo-neutrinos
* Neutrino tomography of the Earth and stars
* Neutrino communication systems
* Reactor neutrinos and control of nuclear reactors

Listed at the Workshop Towards Neutrino Technologies:

http://cdsagenda5.ictp.trieste.it/full_display.php?smr=0&ida=a08170

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